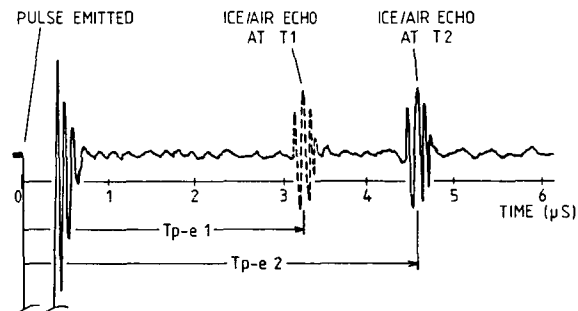
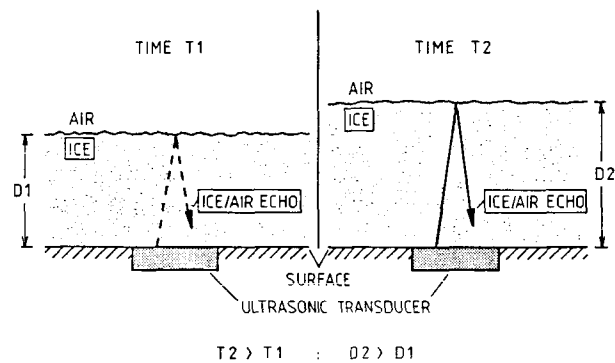


## EXPERIMENTAL METHODOLOGIES TO SUPPORT AIRCRAFT ICING ANALYSIS

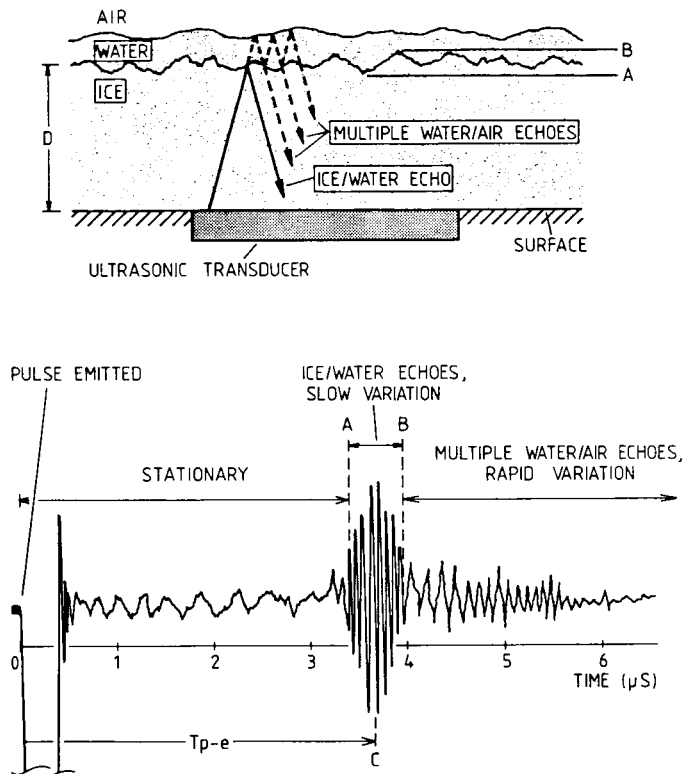
R. John Hansman, Jr. and Mark S. Kirby  
 Massachusetts Institute of Technology  
 Cambridge, Massachusetts

This figure shows typical ultrasonic echo signals for dry "rime" ice growth.

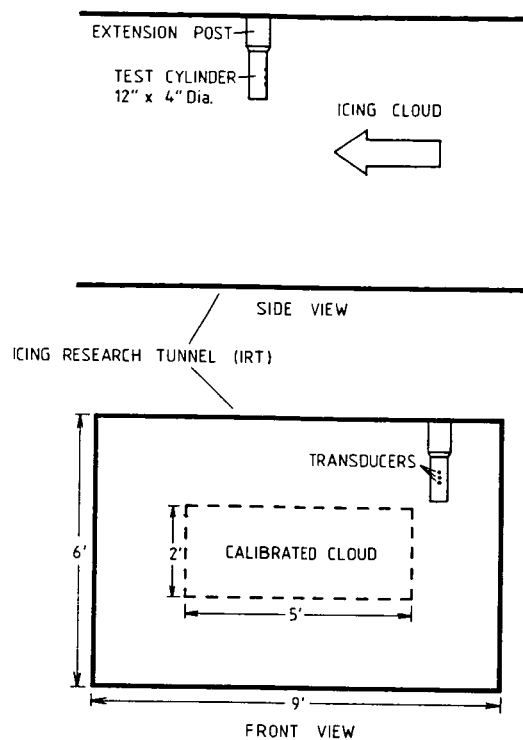


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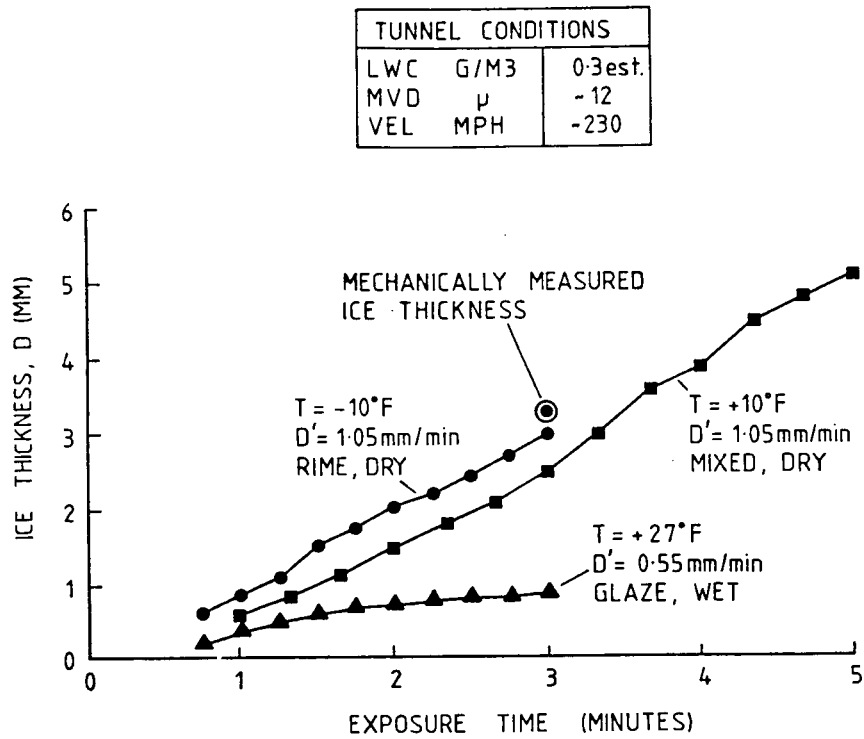
This figure shows typical ultrasonic echo signals for wet "glaze" ice growth. The presence of surface water is identified by multiple echoes in the water layer which have a distinctive frequency behavior resulting from changes in the water layer thickness due to surface waves and droplet impact.



The location of the test cylinder in the tests conducted in the Icing Research Tunnel (IRT) is indicated here.

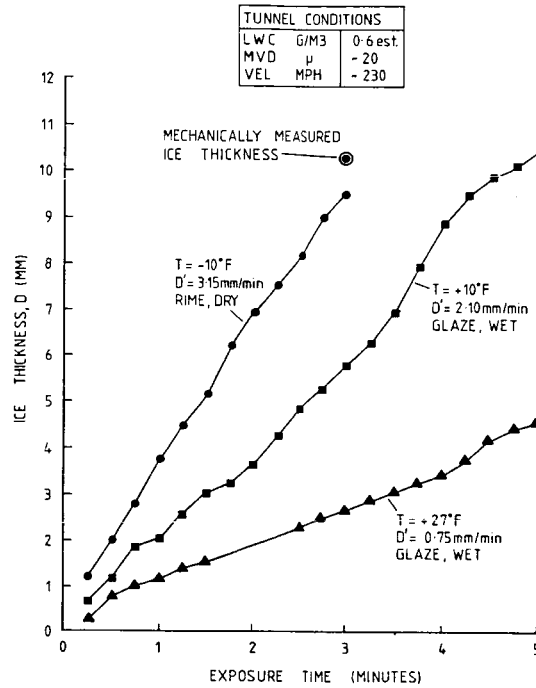


This figure presents ice thickness versus time for light icing conditions measured by ultrasonic transducers on the stagnation line of a 4-in.-diameter cylinder in the IRT.

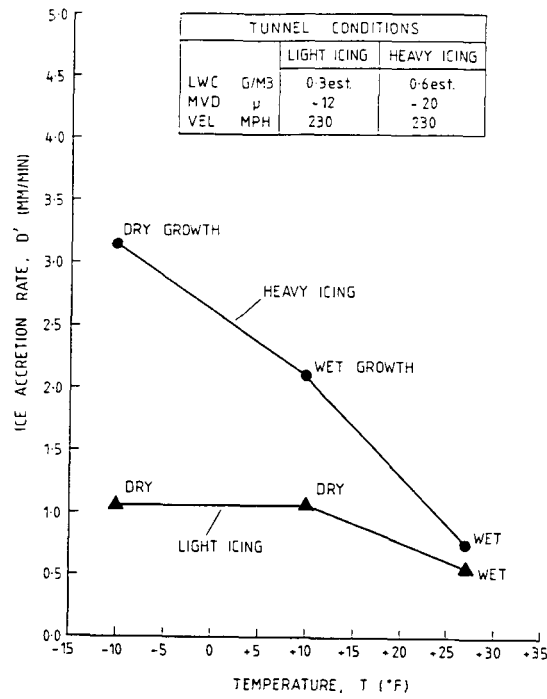


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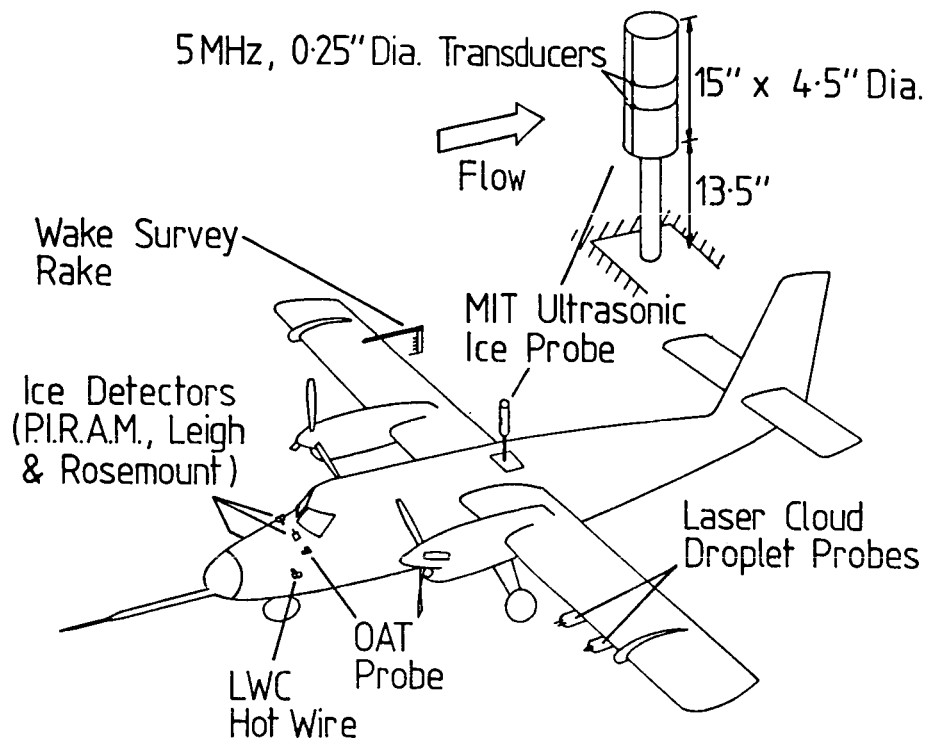
This figure presents ice thickness versus time for heavy icing conditions measured by ultrasonic transducers on the stagnation line of a 4-in.-diameter cylinder in the IRT.



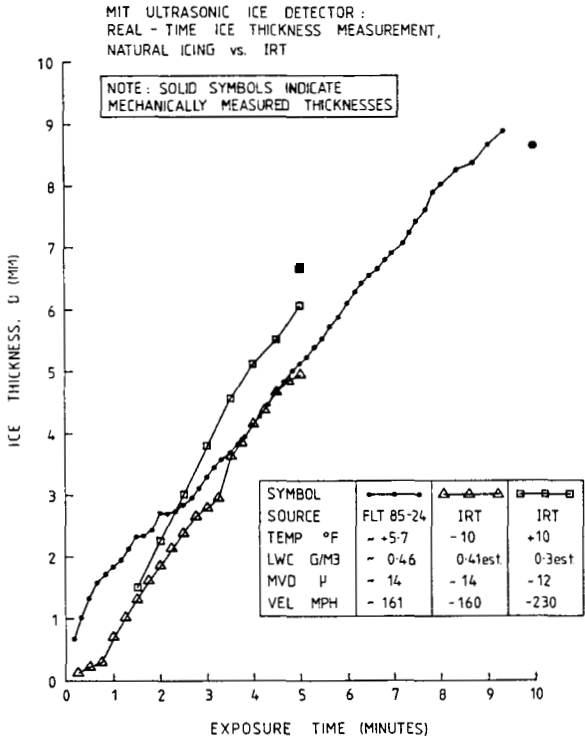
A comparison of ice accretion rates for various tunnel conditions is given in this figure. The accretion rate on the stagnation line is seen to increase with decreasing temperature until dry ice growth is achieved.



This figure shows the experimental configuration for flight tests of the ultrasonic measurement system mounted on a test cylinder which extended through the roof of the NASA Twin Otter Icing Research Aircraft.

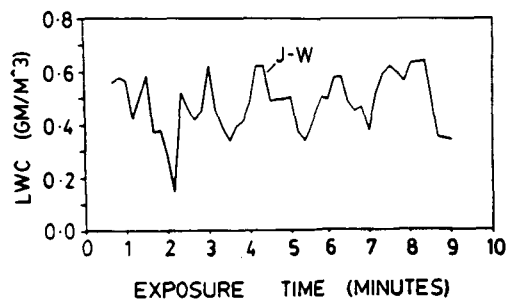
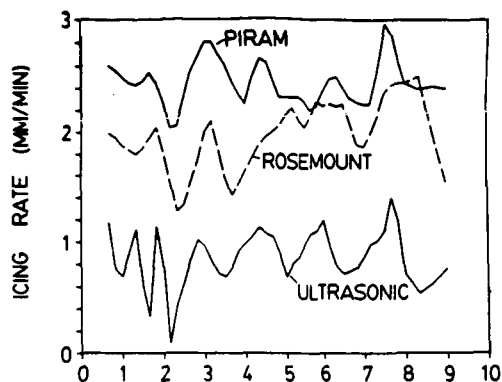


This figure presents a typical plot of ice thickness versus time for natural (flight test) icing conditions. The data shown are from research flight 85-24. Also shown are plots from similar icing conditions in the IRT.

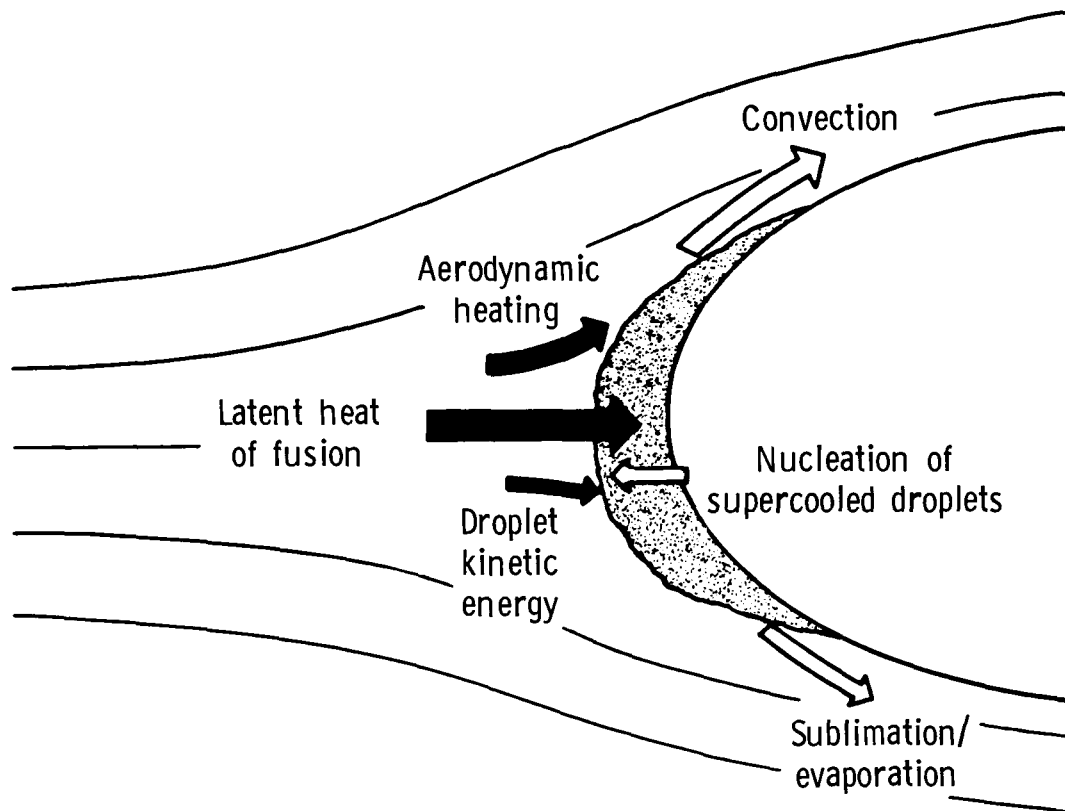




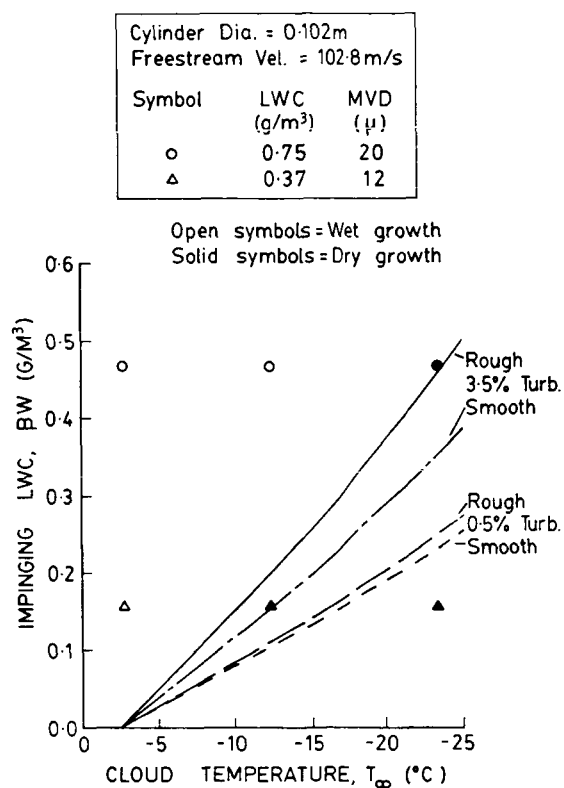
Icing rates versus exposure times (as measured by the MIT ultrasonic, Rosemount and PIRAM detectors on the aircraft for flight 85-24) are shown. Also shown is the cloud liquid water content as measured by the Johnson-Williams probe. For the relatively cold conditions encountered on this flight the icing rate is expected to be directly proportional to the liquid water content.



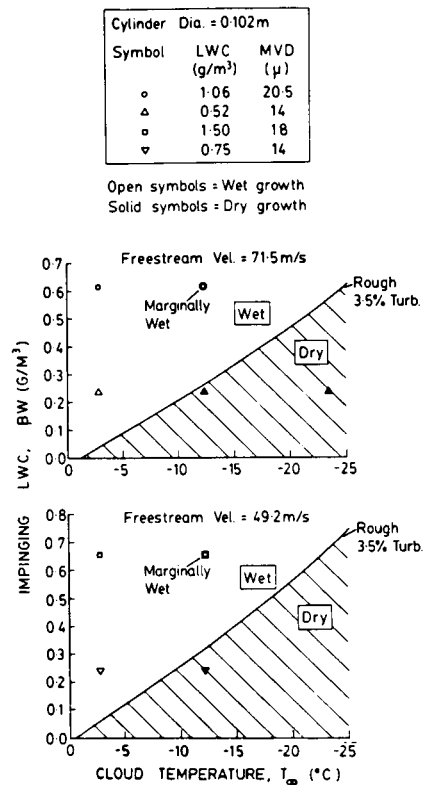
This figure schematically presents the components of the simple heat balance model used to predict wet/dry ice growth. By parametrically comparing the predicted threshold for wet/dry growth with observed wet and dry growths measured by the ultrasonic technique, it is possible to infer data on the heat transfer behavior of the ice surface. This heat transfer behavior is seen as a major area of uncertainty in current ice accretion modeling and scaling efforts.



Wet/dry threshold predictions for several heat transfer coefficients along with measured wet/dry from a series of tests in the IRT at 102.8 m/sec are given in this figure. The best agreement to the data is a high heat transfer coefficient characteristic of a high (3.5%) free-stream turbulence level and a rough surface.



This figure presents wet/dry threshold data for several additional tunnel velocities. The 3.5-percent turbulence model is consistent with the observed data.



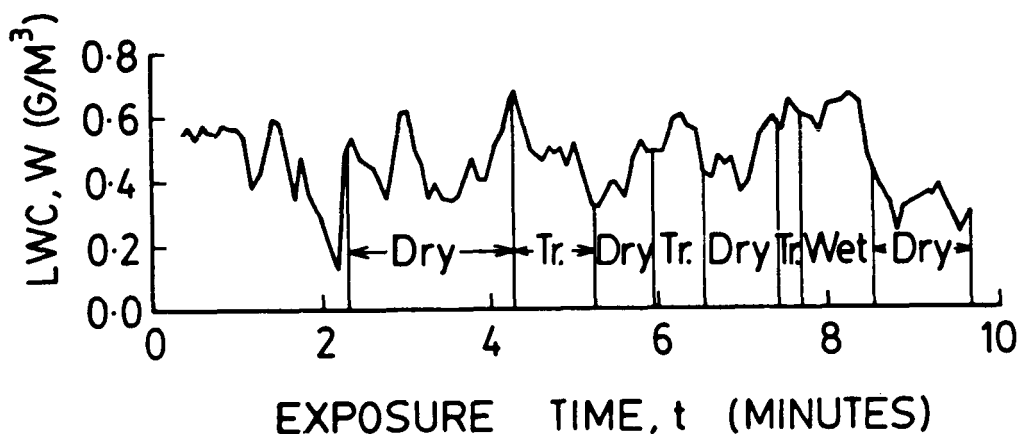
This figure shows the liquid water content versus exposure time for research flight 85-24. Also shown are periods of wet, dry and transitional ice growth. It is important to note that in flight icing conditions the environmental conditions are often unsteady. The fluctuations in liquid water content cause a fluctuating heat load which causes the ice growth to vary from wet to dry in the same flight.

### Flight 85-24

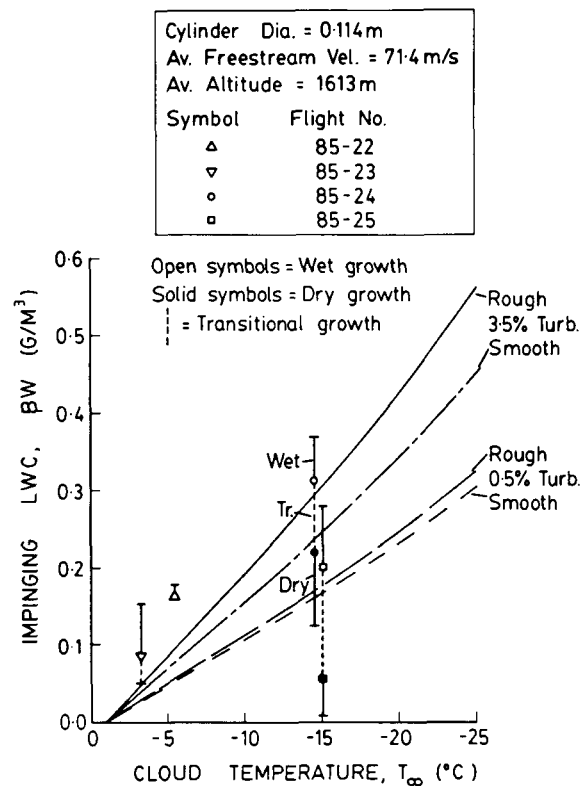
Dry = Dry ice growth

Wet = Wet ice growth

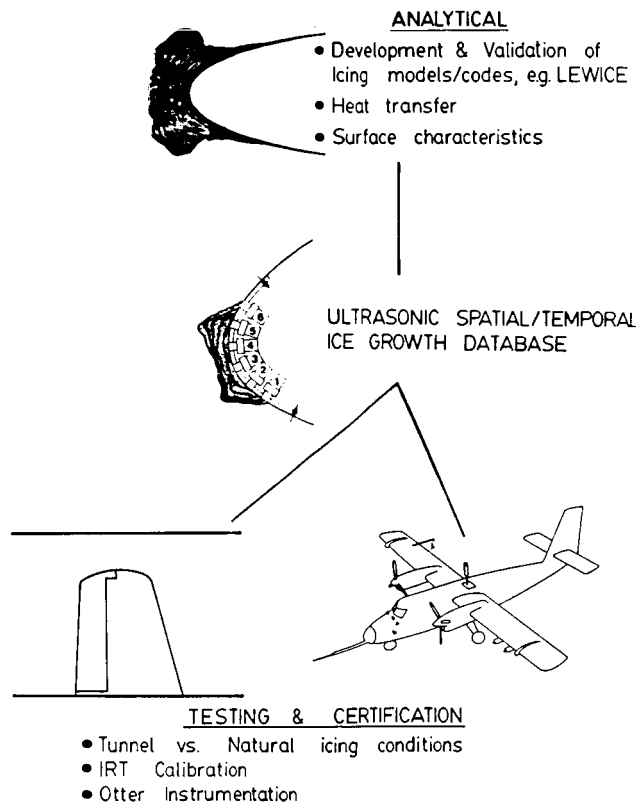
Tr. = Transitional ice growth



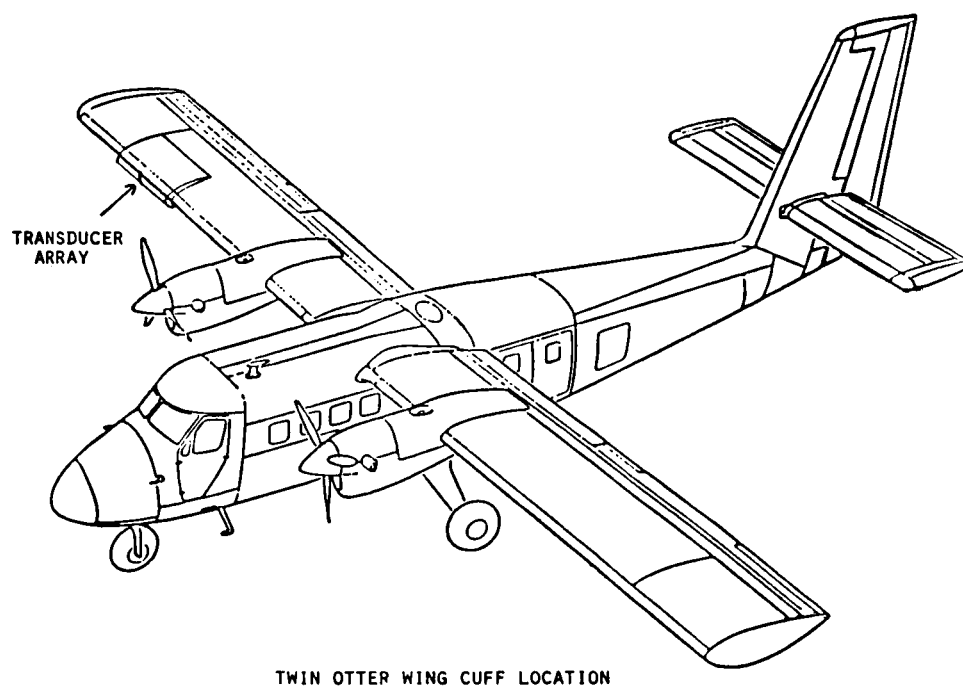
This figure presents wet/dry threshold data for the 1985 flight test series. The heat transfer generally appears to be lower in flight than in the IRT and is consistent with a lower value of ambient turbulence. There is, however, some day to day variation in the heat transfer which is thought to be due to variations in turbulence due to different meteorological conditions. Both the transient nature of the heat load and the effect of variations in the heat transfer due to turbulence level are important to consider when extrapolating wind tunnel results to the flight condition.



The testing philosophy behind the upcoming flight tests where an array of ultrasonic transducers will be flown on a wing cuff mounted on the right wing of the NASA Twin Otter Icing Research Aircraft is depicted. The cuff will be tested both in natural (flight) conditions and in the IRT under similar icing conditions. In addition, the same 2-D airfoil will be subject to analysis by analytical models and scaling criteria. This data set will provide a unique opportunity for the direct comparison of the various icing analysis and certification tools currently being used.



This figure shows the location of the wing cuff on the NASA Icing Research Aircraft.





A schematic view of the data acquisition system to be used in the array flight tests is shown in this figure.

